

SOP-22
Slug Testing

Yerington Mine Site
Standard Operating Procedure

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SOP-22 SLUG TESTING

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1.0 OBJECTIVE

The purpose of this Standard Operating Procedure (SOP) is to promote consistency and quality in the performance of slug testing monitor wells at the Yerington Mine Site in Yerington, NV. The tests are performed to determine hydraulic characteristics of aquifer material and to help understand the dynamics of the movement of groundwater.

2.0 SCOPE AND APPLICABILITY

This SOP: 1) describes the general approach to the performance of slug test, including test applications and data recording requirements; 2) identifies field personnel needed to conduct the tests; and 3) addresses the methods used for the reduction and evaluation of slug test data.

3.0 RESPONSIBILITIES

The Project Manager (PM), or designee, in coordination with the field personnel will have the responsibility to oversee the design, documentation, and oversight of the field work in accordance with this SOP. The field personnel will be responsible for understanding and implementing this SOP during all field activities. Field personnel shall ensure all field activities are documented completely at the end of each field day. Field personnel are responsible for assuring that the original documentation or copies of the field logbook are filed at the end of the project.

4.0 DEFINITIONS

Absolute pressure transducer: A non-vented or “absolute” pressure sensor measures all pressure forces exerted on the strain gauge, including atmospheric pressure.

Aquifer test: A test performed to estimate the hydraulic characteristics of an aquifer.

Falling-head test: A type of aquifer slug test involving the instantaneous introduction of a solid of known volume (or a known volume of water) into a well and the observation of the rate at which the water level returns to static conditions.

Head: Water-level elevation (or height) in a well (or borehole).

Hydraulic conductivity: The quantity of water that will flow through a unit cross-sectional area of a porous medium per unit of time under a hydraulic gradient of 1 at a specified temperature.

Hydraulic gradient: The change in total head per unit of distance in the direction of groundwater flow.

Manual water level: A water level that is taken by hand with a water level meter; usually measured to the hundredth of a foot and reported in feet below measuring point (fbmp).

Measuring Point: The location on the well from which the depth to water measurements should be taken. The measuring point will be designated by a white line marked on the black dedicated bladder pump well cap. If the well does not have a dedicated bladder pump the measuring point will be designated by a black mark on the PVC.

Permeability (intrinsic): The capacity of rock, unconsolidated sediment, or soil to transmit fluids and/or gases under a hydraulic or potential gradient as a function of the extent to which pore spaces are interconnected. It is independent of the nature of the liquid or the potential field.

Radius of influence: The horizontal distance from the center of a well to the limit of the cone of depression. The radius is larger in confined aquifers than in unconfined aquifers, and increases as the cone of depression expands until equilibrium is reached.

Raw data files: Electronic pressure transducer data files that are obtained from pressure transducers or data loggers at a well site. Raw data files are usually binary computer files that can be opened, read, and interpreted only by software developed by the transducer manufacturer. The raw data files must be stored and archived appropriately in order to protect the original data from the pressure transducer. Raw data files contain the raw pressure measurements and date/time stamp from the transducer and may also contain information entered into the transducer software program at the time of installation, such as well name, date/time, measurement interval, reference after elevation at the time of installation, etc.

Real-time data: data that are reported and/or can be viewed while being collected by a data logger.

Rising-head (bail-down) test: A type of aquifer slug test involving the instantaneous removal of a solid of known volume (or a known volume of water) from a well and the observation of the rate at which the water level returns to static conditions.

Rugged Reader: an ultra-rugged, multi-purpose, hand-held PC used to collect, store, and transfer data. Rugged Readers are a product of In-Situ.

Slug: In this document the solid object slug (also known as a mechanical slug) consists of a manufactured “pig” or polyvinyl chloride pipe filled with clean sand, capped with watertight seals, and tied to the end of a rope or cable.

Slug Test: A “slug” test is a common field technique for estimating hydraulic conductivity that is often selected for its ease of implementation. This technique consists of measuring the recovery of fluid head in a well after a near-instantaneous change in

head has been induced by either adding or removing a volume of water or a solid object that displaces water (i.e., the slug).

Specific capacity: The rate of discharge of a well per unit of drawdown, commonly expressed in gallons per minute per foot.

Specific yield: Ratio of the volume of water that soil or rock will yield by gravity drainage to the total volume of the soil or rock.

Splash effect – The disruptive effect resulting from allowing the slug to free-fall into the water, which results in complicated head variations during the initial portion of the slug test. An erroneously large head displacement value will initially occur, with subsequent oscillations that trend downward in magnitude.

Static water level: The level at which water stands in a well or unconfined aquifer when no water is being discharged due to pumping or free flow.

Storage coefficient: Volume of water that an aquifer releases from or takes into storage per unit surface area of an aquifer per unit decline in the component of hydraulic head normal to that surface. For a confined aquifer it is equal to the product of specific storage and aquifer thickness. Storage coefficient is also known as storativity. For an unconfined aquifer it is approximately equal to the specific yield.

Three stage decontamination system: the reduction or removal of chemical agents through use of a three separate one-gallon containers:

- One-gallon deionized water with Liquinox
- One-gallon deionized water for rinse
- One-gallon deionized water for sterilization secondary rinse

Transmissivity: The volume of water (at a specific temperature and viscosity) that will move through a unit width of an aquifer under a unit hydraulic gradient in a unit time period (equals hydraulic conductivity times aquifer thickness).

Water Level: 1) The depth to water (DTW) in a well below ground surface or measuring point expressed in feet and measured to the hundredth of a foot; or 2) the water elevation expressed in feet above mean sea level (ft amsl).

5.0 REQUIRED MATERIALS

The materials required for slug testing at Yerington include:

- Field Notebook

- Field Binder which will include well construction logs, historic water level information, lithologic logs for the screened zone, any well development information available and any well behavioral information noted during sampling.
- Field Forms; attached as Appendix A.
- Water level meter
- Bailers of appropriate sizes to be made into slugs with sand and sealant, used on a one time use basis
- Nylon string
- Transducer and data cable on hose reel (if not already installed in well)
- Rugged Reader
- Duct tape
- Screwdriver
- Large trash bags
- Three stage decontamination system.

6.0 AQUIFER TEST PROCEDURES

Slug tests offer a relatively quick and inexpensive method of estimating the aquifer properties of hydraulic conductivity and (less reliably) storage coefficient for the localized zone surrounding a well. There are advantages to performing slug tests versus pumping tests:

- Slug tests are generally preferred over pumping tests for potentially contaminated aquifers because no or little water is discharged from the well.
- Slug tests can be performed by one person depending on the size of the slug, and the depth, diameter, and accessibility of the well. Deep, large volume wells may require two people.
- Slug tests can also be performed in wells where the aquifer hydraulic conductivity is lower than what is considered suitable for pumping tests.

However, aquifer data collected from slug tests reflect conditions of the material near the well, and they are sensitive to the condition of the gravel pack and any alterations to the aquifer near the borehole. Wells intended for slug test data collection must be carefully designed, installed, and developed. Clay smearing from layers above and below the aquifer test zone, due to inappropriate drilling techniques or overdrilling with auger methods, may lead to erroneous test results. Hydraulic values calculated from the test results will usually be lower than the aquifer material (by a factor of 2 to 3) when there

are inappropriate drilling techniques. If mud rotary drilling was used, the possibility of mud infiltration will cast doubt on the validity of slug test data. A well should be allowed to stabilize at least 24 hours after well development before a slug test is performed.

Slug testing of a well involves either the instantaneous addition or removal of a known volume into the water column, and the measurement of the rate in which the water level returns to its static elevation. For the falling-head slug test, a solid object (slug or "pig") is inserted into the well displacing a volume of water equal to the volume of the slug causing the water level in the well to rise. Once the water level has returned to static conditions, the slug is rapidly removed to simulate the instantaneous removal of the same volume of water. For a rising-head slug test (or bail-down test), a slug of water is removed from the well using a bailer. The hydraulic conductivity of the aquifer material is calculated from the rate that the water level returns to static conditions. The method of solution is the same for both the addition and removal of the slug. Each analysis can be used to confirm the results obtained from the other.

The slug test method was developed for fully penetrating wells in confined aquifers of rather low transmissivity ($<7,000 \text{ ft}^2/\text{day}$). For partially penetrating wells, the value of the transmissivity would apply to the part of the aquifer in the screen zone. Application of the method to wells in unconfined aquifers, where the wells are screened across the water table, requires considerable judgment and results should be regarded with skepticism (Lohman, 1979). For unconfined aquifers, where the wells are screened across the water table, falling head test should not be performed because the test methodology cannot account for unsaturated conditions. Therefore, under these conditions a rising head test should be conducted. For unconfined aquifers, where the wells are screened below the water table, it is recommended that both rising and falling tests be conducted.

The time required for a slug test to provide sufficient data is related to the volume of the slug, the transmissivity of the aquifer, and the construction of the well. These factors must be combined to allow incremental changes in groundwater levels to be measured by practical means. In wells constructed in high permeability zones, re-equilibration of the water level may occur within 10 minutes. Lower permeability zones may take longer, but usually re-equilibration will occur within 15 to 30 minutes, thus allowing duplicate tests of several wells to be run within a short time period.

More details concerning the slug test methods, such as an over-damped and under-damped well response, are presented in the Field Procedures for Instantaneous Change in Head (Slug) Tests for Determining Hydraulic Properties of Aquifers (ASTM D 4044-96, 2002).

6.1 Slug Test Equipment


The following equipment will be used while performing slug tests in Yerington:

- Water level meter
- LevelTroll 300 absolute pressure transducer with data cable (or equivalent)
- Rugged Reader (or equivalent)
- Slug – a bailer weighted with clean sand that is sealed water tight.
- Stopwatch and/or clock

6.2 Falling and Rising Head Slug Test Procedures

The following procedures apply to conducting a falling-head (slug lowered into the well) and a rising-head (slug removed from the well) slug test using a data logger system to record the water levels. Use the field form included as Attachment A where applicable.

1. Review well construction records and development information for the well to be tested. They will be located in the field slug testing binder.
2. Open the well head.
3. Locate the measuring point on the well. The measuring point is typically indicated by a black line or other mark on the PVC well casing or on the PVC well cap. Insert the water level meter through the large hole in the well cap and lower meter to water surface.
4. Collect a manual water level reading measured to a hundredth of a foot using a 200' water level meter from the measuring point on well. The sensitivity setting for the water level meter for the site is typically low, 2 or 3. If the well was not vented to atmospheric pressure, take a few readings and make sure the water level has equilibrated. Compare the water level measurement to historic data as a check for accuracy.
5. If the well has a dedicated bladder pump it may need to be removed. Coil the tubing onto a hose reel and be careful not to let it touch the ground. When the pump is out of the well be sure to cover it and, if possible, cover the reel too with a large trash bag.
6. Make sure the transducer is properly connected to the data cable. Connect the data cable to the communication cable. Connect the Rugged Reader to the data cable, and make sure there is communication with the transducer.
7. Attach weight to the transducer so that when pulling the slug out of the water the transducer is less likely to be pulled up with the slug.
8. Lower the transducer down the well and place it at least 2 feet deeper than the length of the slug, but should not exceed the maximum design depth for the transducer used.

9. If necessary, cover sharp edges of the well casing with duct tape to protect the transducer cables.
10. Fasten the transducer data cable at the top of the well with a screwdriver, tape or well dock so it cannot move. Be careful not to bend the data cable too far as this can damage the cable. Do not force it to bend.
11. Let the transducer equilibrate to the temperature of the well for at least a ½ hour.
12. Measure the groundwater level again with the water level meter to see if the level has returned to equilibrium after the insertion of the transducer in the water (and the removal of the pump if applicable).
13. If not already connected, electronically connect the transducer to the Rugged Reader by clicking the connect icon; i.e. .
14. Synchronize the Rugged Reader and transducer clocks. Check to see if both power and memory bars are adequate.
15. If the transducer is currently logging (i.e., if the transducer is dedicated to that well) first stop and download the log, then set up a new log for the rising head slug test. Record the filename on the field form.
16. Continue setting up a new log by selecting all three parameters to record with units of PSI for pressure, C for temperature, and feet for level.
17. For the log type select 'Fast Linear' and select a logging rate of 1 reading per second.
18. Set the test for 'manual test start'.
19. Set the level reference to Surface Elevation. Set the reference value to 100 so that no negative values will be recorded and 90% recovery is easily observable. The 100 value will be subtracted during the data reduction and evaluation phase.
20. Check the current depth of the transducer and record on the field form.
21. Set the specific gravity value to fresh water.
22. Review the settings on the summary page.
23. Measure the rope or cable that will support the slug from the top of the protective surface casing.
24. Attach one end of the rope to the slug and tie the other end at the well head or surface casing.
25. Lower the slug into the well and place the slug just above (3-5 feet) the water level.
26. Click the play button on the Rugged Reader to start recording the test.

27. Lower the slug quickly into the well. Avoid dropping the slug any distance into the water to prevent splash and oscillations that can yield erroneous data at the start of the test. If necessary, tie the slug off at the well head.
28. Once the water level has recovered to within 90% of the static water level, the slug-in (falling-head) portion of the test can be considered complete. Sufficient time should be allowed for the water level to recover to a static condition before starting the slug-out (rising-head) portion of the test.
29. Quickly pull the slug out of the water.
30. Continue to measure the water level until it has returned to within 90% of static conditions.
31. Stop the transducer from logging. Download the data file from the transducer and record the filename on the field form. Perform an initial data quality check by viewing the data file on the Rugged Reader in graph mode.
32. Repeat steps 24 through 30 as necessary in order to collect enough tests for QC purposes.
33. If necessary, retrieve the transducer from the well and decontaminate both the transducer and the data cable via the three stage decontamination system.
34. If necessary, replace the dedicated bladder pump into the well being careful not to contaminate the pump with dirt.
35. Decontaminate the water level meter.

The data collected using the transducers for the slug tests should be reviewed in the field in order to assess if the test should be repeated. At the end of each day archive the data onto a CD.

7.0 DATA REDUCTION AND EVALUATION

The method used for evaluating the slug test data will depend on how the aquifer responds to the slug tests (i.e. the shape of the water-level response curve). A program will be used for data evaluation. The program will provide the following Slug test analyses to be used as appropriate:

Hvorslev, 1951. Time lag and soil permeability in ground-water observations.

Bouwer & Rice, 1976. Slug test for determining hydraulic conductivity of unconfined aquifer with completely or partially penetrating wells.

Black, 1978. The use of the slug test in groundwater investigations (Modified Bouwer & Rice unconfined aquifer slug test analysis using an exponential type curve).

Cooper, Bredehoeft & Papadopoulos, 1967. Response of a finite-diameter well to an instantaneous charge of water.

Hyder, Butler, McElwee & Liu, 1994. Slug tests in partially penetrating wells (KGS Model including well skin and monitoring well response).

8.0 QUALITY ASSURANCE/QUALITY CONTROL

Quality assurance activities that apply to conducting these procedures are located in the site QAPP, including record keeping such as field notes and field forms. In addition, the following general procedures apply:

- All data must be documented on field data sheets or within site logbooks.
- All instrumentation must be operated in accordance with operating instructions as supplied by the manufacturer, unless otherwise specified in the work plan.

9.0 REFERENCES

Brown and Caldwell, 2007c, *Second-Step Hydrogeologic Framework Assessment (HFA) Yerington Mine Site, Lyon County, Nevada*. Prepared for the Atlantic Richfield Company.

Brown and Caldwell, Revision 2, 2007, *Draft Quality Assurance Project Plan*. Prepared for Atlantic Richfield Company.

Brown and Caldwell, 2007, *Standard Operating Procedure: Slug Testing*. Internal Document.

In-Situ Inc, 2007. *Level TROLL Operator's Manual*. http://in-situ.com/In-Situ/Downloads/Downloads_OpManuals.php

In-Situ Inc, 2007. *Blue Rugged Reader Operator's Manual*. http://in-situ.com/In-Situ/Downloads/Downloads_OpManuals.php

In-Situ Inc, 2007. *Slug Testing Application: Using In-Situ LevelTROLL Probe and AQTESOLV Software*. http://in-situ.com/In-Situ/Downloads/Downloads_OpManuals.php

Norwest Applied Hydrology, 2007, *Field Sampling Plan for Groundwater Monitoring Wells Yerington Mine Site*. Prepared for Atlantic Richfield Company.

US EPA SOP#2046. *Slug Tests*.

Weight, W. and Sonderegger, J., *Manual of Applied Field Hydrogeology.*, McGraw-Hill, 2001

10.0 ATTACHMENTS

Attachment A – Slug Test Field Data Form

ATTACHMENT A

SLUG TEST FIELD DATA FORM

Project #: _____

Well ID: _____

Date/Time: _____

Personnel: _____

Data Logger ID: _____

Slug Volume: _____ ft³

Test Method: Rising Head

___ Falling Head

Other: _____

Static Depth to Water: _____

Ref Elevation: _____

Start Time Test #1: _____

Start Time Test #2: _____

End Time Test #1: _____

End Time Test #2: _____

[illegible]

Comments: _____
